

## APPENDIX D

## SUMMARY OF THE RAPID SEISMIC ANALYSIS PROCEDURE

**D-1. Introduction**

This appendix summarizes the rapid seismic analysis procedure (RSAP) developed by the Naval Civil Engineering Laboratory (NCEL) for the Naval Facilities Engineering Command (NAVFACENGCOM). The RSAP is preceded by computer and on-site screening at which time site hazards are identified. The RSAP is intended to identify buildings that are either liable to be severely damaged or only lightly damaged. It is a further screening tool. A complete description of this procedure is given in the NCEL Technical Memorandums TM No. 51-78-02 and TM No. 51-83-07. Examples showing the analysis of a steel and a concrete building are given in paragraph D-9.

**D-2. Background**

The RSAP was initially developed by John A. Blume & Associates in a pilot study of a relatively large number of buildings at Puget Sound Naval Shipyard in 1973. The procedure was formalized by NCEL.

*a. Seismic investigation of an activity.* The seismic investigation is divided into two phases. In Phase I the selected buildings at the activity are analyzed approximately by RSAP. Phase I parallels chapters 2, 3, and 4 of this manual. Those buildings found to be inadequate to Phase I are analyzed in detail in Phase II to determine the degree of strengthening required and to estimate costs of upgrading. Phase II parallels chapters 5, 6, and 7 of this manual.

*b. RSAP.* The main purpose of the RSAP is to identify those buildings that may be susceptible to severe damage. The major steps of the RSAP are shown in table D-1. The procedure has the same development roots as the procedures covered by chapters 2, 3, and 4 of this manual. The major modifications that NCEL made to the basic rapid analysis procedure follow:

(1) Systemization of the analysis of the facility inventory assets at a Naval installation.

(2) Development of the response spectra for the design earthquakes. This procedure has since been formalized by the Tri-Services Committee and is covered by NAVFAC P-355.1 (e.g., SDG).

(3) Automation of computation of shear stiffnesses for concrete or masonry buildings, the first mode shape and natural period of multi-story buildings, and estimation of building damage from

the response spectra.

(4) Enhance the RSAP with the following modifications:

(a) Criteria for field screening.

(b) Criteria for eliminating buildings from further investigation in the rapid analysis.

(c) Modified criteria for determining structural properties including damping values, natural periods and base shear capacities.

(d) Modified criteria for determining the site demand from the response spectra at the ultimate base shear capacity for certain systems.

(e) Criteria to aid the selection of buildings for detailed analysis.

(f) Criteria to aid in evaluating the adequacy of the lifeline utilities at a given Naval activity.

**D-3. Selection of buildings**

The selection procedures of the RSAP includes provisions for inventory reduction, field screening, gathering of structural drawings and calculations, a visual inspection of the selection buildings, and a cursory survey of the site geological hazards.

*a. Inventory reduction.* A procedure and criteria are presented in the RSAP references to facilitate the selection of the buildings for the visual screening. With the issue of this manual, the RSAP criteria are superseded by the screening procedure of paragraph 2-3 of this manual.

*b. Field screening.* The RSAP references recommend criteria for eliminating buildings from further investigation. These decisions are made after the brief survey to determine physical conditions and after a brief examination of construction drawings. The criteria are similar to those provided in paragraph 3-2 of this manual.

*c. Visual inspection of selecting buildings.* A final visit is made to verify that buildings are built as shown on the drawings, especially the lateral-force resisting elements. This step of the RSAP is similar to the first two steps of the preliminary evaluation described in paragraphs 4-2a and 4-2b of this manual.

*d. Site geological hazards.* During the site visits, a cursory survey should be made of the potential seismically-induced geological hazards based on the available geologic subsurface information. These hazards include faults and fault rupture, liquefaction, landslide and lateral spreading, ground cracking, compaction settlement, tsunamis, and seiches.

Table D-1. Major steps of the Rapid Seismic Analysis Procedure (RSAP)

Preliminary

- o Visual survey of the lifeline utility system.
- o Screening.
- o Selection of buildings.

RSAP

- o Determination of the site elastic response spectra.
- o Determination of the structural properties at yield and ultimate levels for the transverse and longitudinal directions.
- o Estimation of damage from the structural capacities and demands from the response spectra.

Follow-Up

- o Selection of buildings for detailed analysis.
- o Follow-up investigation of site hazards.

**D-4. Determination of response spectra**

Site specific elastic response spectra for single degree-of-freedom systems are determined in accordance with the procedures given in the SDG, chapter 3, appendix C and appendix D. The NAVFAC ground motion criterion for the RSAP is a maximum ground acceleration having a 20 percent probability of exceedence in 50 years. (Note, this differs from the provisions in this manual, which specifies EQ-II. EQ-II has a 10 percent probability of not being exceeded in 100 years.)

*a. Sample response spectra.* Figure D-1 shows the resulting response spectra for an intermediate soil site with a maximum ground acceleration of 0.25g. The curves in the figure are used for determining the seismic demands (loading) on the buildings. These spectra are used for the examples of the RSAP given in paragraph D-9.

*b. Acceptable capacities.* Buildings with spectra acceleration capacities at ultimate that satisfy the site demands at ultimate according to the ground motion criterion are considered fully acceptable. Those buildings whose spectral acceleration capacities at ultimate are 75 percent of the demands at ultimate are considered marginal.

*c. Variation in force levels.* It is recommended that damage estimates be made for a few force levels below and above the 80 percent/SO year level. These estimates provide a profile of the expected seismic response of the building. This

recommendation is similar to those in paragraph 4-2d(6) of this manual.

**D-5. Determination of structural properties at yield and ultimate levels**

The damping values, the natural periods, and the base shear capacities are determined for the transverse and longitudinal directions of the building.

*a. Damping values.* The assumed damping values used in the RSAP are given in table D-2.

Table D—2. Damping values

<u>Type</u>	Percent of Critical	
	<u>Yield</u>	<u>Ultimate</u>
Steel	5	10
Concrete	5	10
Wood	10	20
Masonry	5	10

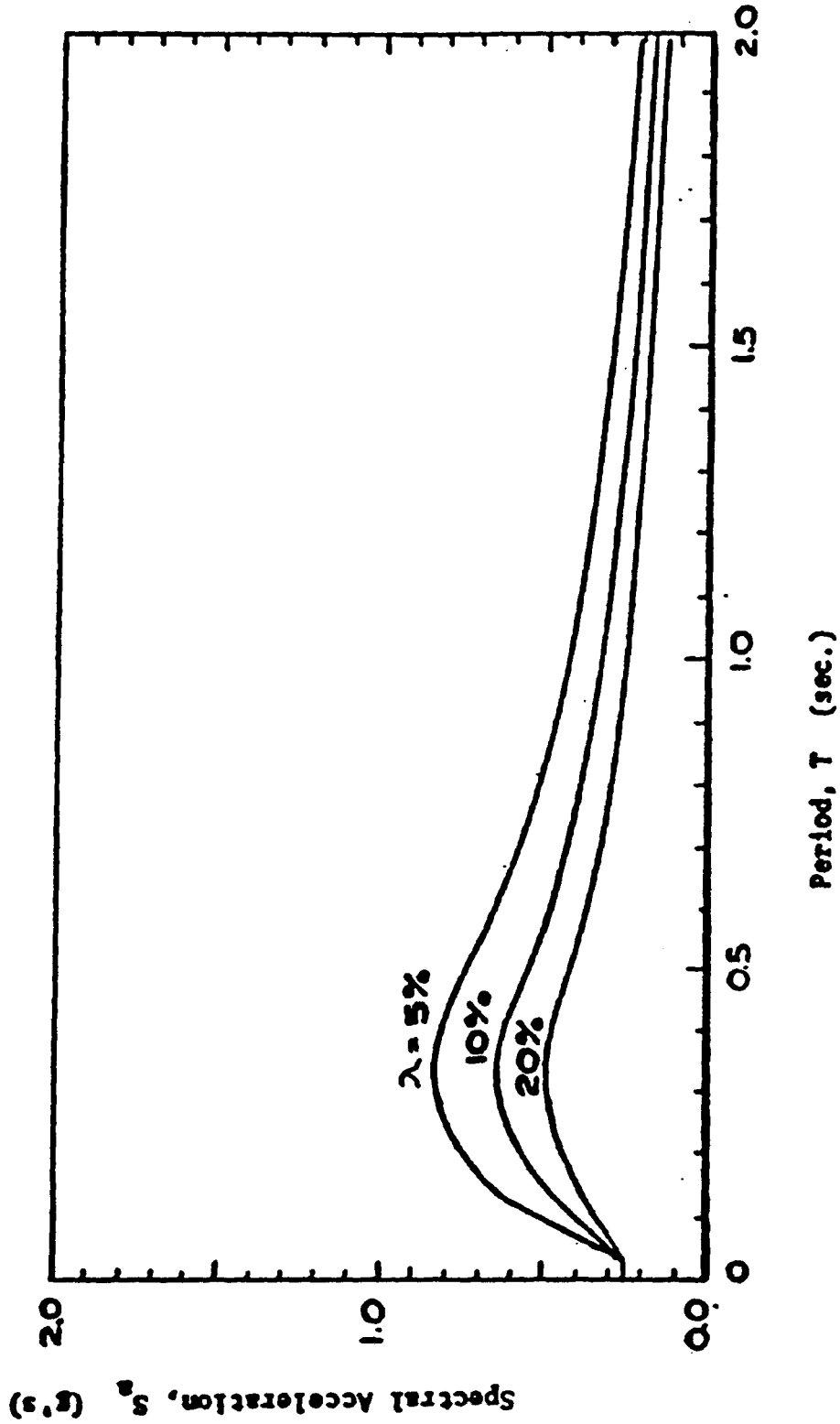


Figure D-1. Site response spectra for a Naval activity in southern California

(Note, these vary from the values given in table 4-2 of this manual.) The damping value increases from the yield to the ultimate level due to the inelastic deformation of the structural and non-structural elements of the building.

b. *Natural periods.* Natural periods of the building in the transverse and longitudinal directions are determined from the following equations:

(1) Yield Level:

$$\text{Empirical: } T_Y = C \left( \frac{0.05 h_n}{\sqrt{D}} \right) \quad (\text{eq D-1})$$

$$\text{Theoretical: } T_Y = 2 \pi \sqrt{\frac{m}{k}} \quad (\text{eq D-2})$$

$$\sum_{i=1}^n w_i \delta_i^2$$

$$T_Y = 2 \pi \frac{1}{g \sum_{i=1}^n f_i \delta_i} \quad (\text{eq D-3})$$

(2) Ultimate Level:

$$T_U = T_Y \sqrt{\mu \frac{S'_{aY}}{S'_{aU}}} \quad (\text{eq D-4})$$

- where  $h_n$  = height of building (ft)  
 $D$  = width of building in the direction considered (ft)  
 $C$  = a constant between 0.75 and 1.5 to account for building mass and stiffness  
 $m$  = seismic mass  
 $k$  = stiffness of the building in the direction considered  
 $w_i$  = weight of the building at level "i"  
 $\delta_i$  = elastic deformation at level "i" using the applied lateral forces  $f_i$   
 $f_i$  = approximate lateral force distribution consistent with the assumed fundamental mode shape  
 $\mu$  = ductility factor equal to ratio of maximum displacement to yield displacement  
 $S'_{aY}$  = spectral acceleration capacity of the building at yield level  
 $S'_{aU}$  = spectral acceleration capacity of the building at ultimate level

(3) Equation D-1 is obtained by multiplying equation 3-3A of NAVFAC P-355 (e.g., BDM) by the constant C to account for the different building masses and stiffnesses. Equation D-2 is the natural period for a single degree-of-freedom system.

(4) Equation D-3 is the Rayleigh equation 3-3

of the BDM. The weight of the building is approximated by assuming unit weights for the roof framing, floor framing, wall, actual live loads (if any), and other miscellaneous items.

(5) The natural periods of the building at the ultimate level,  $T_U$ , are computed from the periods at the yield level,  $T_Y$ , by using equation D-4. The range of the recommended ductility factors,  $\mu$ , are given in table D-3.

Table D-3. Ductility factors

Type	$\mu$
Steel	4-6
Concrete	3-4
Wood	3-4
Masonry	2-3

c. *Base shear capacities.* After reviewing the field survey notes and the construction drawings, rough sketches of typical plans and elevations of each building are made to determine the primary lateral-force resisting system or systems. The yield and ultimate base shear capacities of a building are computed by summing the contributions from the vertical lateral force-resisting elements of the building in the transverse and longitudinal directions and dividing the results by the seismic weight of the building. The horizontal lateral-force resisting elements such as beam, girders, floor and roof diaphragms are only considered indirectly in the analysis by examining the effectiveness of their connections to the vertical lateral-force resisting elements.

(1) *Yield capacity.* The yield capacity of a building is defined as the lateral-force required to cause the significant yielding of the most critical, not necessarily the most rigid, component of the lateral-force resisting system.

(2) *Ultimate capacity.* The ultimate capacity of a building is defined as the lateral-force required to cause yield initiation of the most flexible component of the lateral-force resisting system of the formation of a collapse mechanism.

(3) *Examples.*

(a) A steel building with a lateral-force resisting system consisting of infill brick walls and X-

braces may behave as follows in resisting seismic forces. The brick wall and X-braces may act together in resisting the seismic forces until cracking of the brick wall is initiated. Then the X-bracing and columns (only after the yielding of the X-braces) will take more and more of the seismic loading until they fail.

(b) For a reinforced concrete building with shear walls, the shear walls will resist most of the seismic loading until they have started to crack. Thereafter, the frames will start to resist on increasing portion of the loading. For reinforced concrete frame and/or shear wall and reinforced masonry buildings, the ultimate base shear capacity,  $C_{BU}$ , is computed first. Then, the yield base shear capacity,  $C_{BY}$ , is obtained by dividing  $C_{BU}$  by a load factor 1.5.

(c) Wooden frame buildings with shear panels will behave like the concrete frame and shear wall buildings.

*d. Spectral acceleration capacities.*

(1) Before they can be used for estimating the earthquake damage, the base shear capacities  $C_{BY}$  and  $C_{BU}$  must be transformed to the spectral acceleration capacities  $S'_{aY}$  and  $S'_{aU}$  using the following equations:

$$S'_{aY} = \alpha C_{BY} \quad (\text{eq D-5})$$

$$S'_{aU} = \alpha C_{BU} \quad (\text{eq D-6})$$

(2) The constant  $\alpha$  in the equations depends on the mode shape and mass distribution. The great majority of the Navy buildings are less than three stories high and can be classified as low-rise ( $\leq 6$ -story). The  $\alpha$  constant for low-rise buildings ranges between 1.05 and 1.18, with the larger value for the taller buildings. For conservatism and simplicity,  $\alpha$  is assumed to be one in most cases. (Note,  $\alpha$  as used in this appendix is the inverse of  $a$  used in the SDG and in table 4-1 of this manual.)

## D-6. Estimate of damage

Earthquake damage is estimated from the demands of the response spectra using the damping values, natural periods, and spectral acceleration capacities of the building.

*a. Damage assumption.* Until yield capacity of the building is reached, damage is assumed to be equal to zero and ductility factor equal to one. When the ultimate capacity is reached, damage is assumed to be equal to 100 percent and ductility factor equal to the maximum value. For intermediate values of capacity, damage assessment is necessarily somewhat subjective and depends on many factors not amenable to analytical treatment. For the rapid analysis, damage is assumed to vary linearly between the yield capacity,  $S'_{aY}$ , and the ultimate capacity,  $S'_{aU}$ , as shown in figure D-2.

*b. Damping assumption.* Another assumption

required for estimating damage is the amount of damping during the response of the building. Damping is assumed to be a constant up to the yield capacity. Above yield, the damping increases because of energy absorption and dissipation from inelastic response. The damping values used in the rapid analysis were given in table D-2. Furthermore, damping is assumed to vary linearly between the yield and ultimate capacities of the building.

*c. Damage estimating procedure.* The procedure for estimating damage is based on the reconciliation of the site demands,  $S_{aY}$  and  $S_{aU}$ , and the spectral acceleration capacities of the building,  $S'_{aY}$  and  $S'_{aU}$ . The procedure is illustrated graphically in figure D-2. The spectral acceleration capacities of the building are denoted by the open circles at the natural periods shown. The corresponding site demands are denoted by the black dots. The intersection of the two lines defined by the two sets of points determines the estimated damage of 60 percent. This procedure is essentially the same as the capacity spectrum method of the SDG that is described in paragraph 4-2d of this manual.

*d. Modification to damage estimation procedure.* After performing the rapid seismic analysis on a fairly large number of steel buildings and wooden buildings, comparisons of the RSAP damage estimates with damage observed in major earthquakes for buildings of similar construction indicated that the estimated damage were much higher than the observed. More realistic damage estimates were obtained by applying a reduction factor  $R_U$  to the ultimate site demands for steel, wooden, and reinforced concrete and reinforced masonry buildings with better-than-average reinforcement detailing.

(1) The reduction factor  $R_U$  is used to account for energy absorption and dissipation from inelastic seismic response of the building during actual earthquakes not accounted for by the lengthening of the natural periods and increase in damping from the yield to the ultimate level. The following  $R_U$  values are recommended:

(a) Steel Buildings:  $R_U = 5.0$ .

(b) Wooden Buildings:  $R_U = 5.0$  for those buildings with a large number of interior partitions. For wooden warehouses and large-span wooden structures,  $R_U = 1.5$ .

(c) Reinforced Concrete and Masonry Buildings:  $R_U = 1.5$  for those buildings with better than-average detailing than required by code during their design. Otherwise,  $R_U = 1.0$ .

(2) An illustration of the effect of  $R_U$  on the estimated damage is shown in figure D-2. With  $R_U$  of 5.0, the estimated damage is reduced from 60 percent to 34.4 percent.

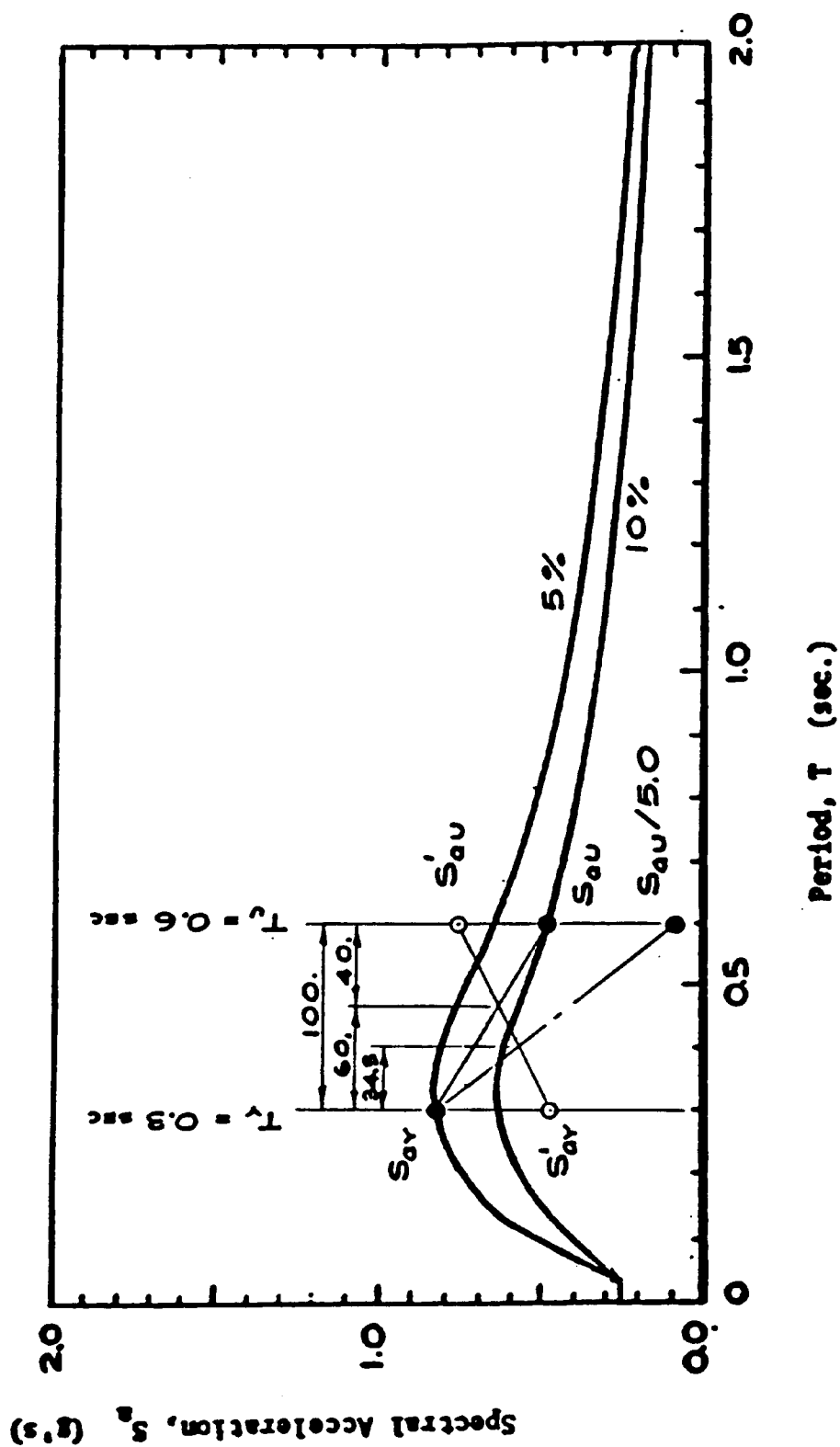


Figure D-2. Graphical illustration of damage estimation

*e. Combined building damage estimate.* For each building, damage is computed for the transverse and longitudinal directions. To determine the combined damage for the building, it is assumed that one-third of the building depends on the lateral-force resisting system in each principal direction and one-third depends on both directions. That is, if a lateral-force resisting element required to provide seismic resistance in both directions is damaged by earthquake ground shaking in one direction, it is also damaged in the other direction. Combined damage for the building is obtained by taking two-thirds of the damage in the more critical direction and adding one-third of the damage in the other direction. For instance, if the damages are 60 percent and 30 percent in the transverse and longitudinal directions, the combined damage is 50 percent. (Note, this is essentially the same as paragraph 4-2d(5) of this manual.)

*f. Computer aided procedure for damage estimates.* When computing damage estimates for many buildings and/or at many different ground acceleration levels, the computation is best done by a computer program. NCEL has developed computer program GEL 9 to do the calculations. The site identification, maximum site ground acceleration, digitized site response spectra, building identification, damping values, natural periods, and spectral acceleration capacities at the yield and ultimate levels for the transverse and longitudinal directions, and the replacement cost are input into the computer. The program computes the estimates damage and cost for the building at the maximum site ground acceleration. The damage cost is obtained by multiplying the estimated percent damage by the replacement cost. In addition, the program computes damage estimates for maximum ground accelerations between 0.05 and 0.50g at 0.05g increments. A sample output from the program for a steel building is given in table D-4.

*g.* In general, the successful application of the rapid seismic analysis procedure demands experience in seismic design and construction and good engineering judgment.

## **D-7. Selection of buildings for detailed analysis**

Based on the results from the rapid analysis, the following guidelines are used in selecting buildings for detail analysis:

*a.* Buildings with greater than or equal to 60 percent combined damage under the maximum site ground acceleration would definitely require detail analysis.

*b.* Buildings with greater than 30 percent combined damage may warrant detail analysis.

*c.* Buildings with relatively poor structural connections may require detail analysis, even if the combined damage is less than 30 percent.

*d.* Essential buildings and other structures that are required to remain functional during and after a major earthquake are analyzed in detail as for new buildings according to the criteria given in NAVFAC P-355.1 (e.g., SDG). Variance from the criteria is allowed only with the consent of the approving authority.

## **D-8. Visual survey of lifeline utilities**

If an activity is to remain functional before and after an earthquake, the lifeline utility systems and the mechanical and electrical equipment must also remain functional. As a part of the rapid seismic analysis, a cursory survey is made of the lifeline utility system to determine its adequacy. The lifeline utility system at an activity includes:

- Energy
- Water
- Sewer
- Communication
- Transportation

*a. Network of utility elements.* The effects from the failure of an utility element of the lifeline utility system is different than the failure of a building in an activity with many buildings. The failure of a building generally has little or no effect on the surrounding buildings, except in case of fire. By contrast, the utility elements are part of a network. The failure of one element can have an immediate effect on the function of the whole network. A discussion of lifeline utility problems in past earthquakes and solutions is given in NCEL TM No. 51-83-07.

*b. Administrative measures.* The following administrative measures are recommended to minimize effects from earthquake damage to lifeline utilities on the mission of an activity:

(1) Analyze and strengthen inadequate structures.

(2) Provide adequate seismic bracing and/or anchorage to utility equipment and storage facilities (see chapters 3 and 10 of the BDM and chapter 6 of the SDG for examples).

(3) Provides standby emergency power, water, materials, storage facilities, and alternative utility routes to insure rapid restoration capacity.

(4) Develop disaster recovery strategies.

(5) Coordinate emergency planning with other military activities.

Table D-4. Sample output of damage estimate for a steel building from computer program CEL 9

DAMAGE ESTIMATES FOR VARIOUS LEVELS OF EARTHQUAKE

DAMAGE ESTIMATE FOR VARIOUS BUILDINGS AT NSY LONG BEACH

RLOG 132 MACHINE TOOL AND ELECTRO SHOP

BUILDING PROPERTIES AND DAMAGE ESTIMATE FOR A NOMINAL ACCELERATION OF 0.25 G

	PERIOD (SEC)	DAMPING	SA STR CAPACITY	SA SITE DEMAND	R
TRANSVERSE DIRECTION			(G)	(G)	
YIELD LEVEL	2.430	0.05	0.130	0.169	
ULTIMATE LEVEL	3.640	0.10	0.160	0.002	5.000
LONGITUDINAL DIRECTION					
YIELD LEVEL	0.620	0.05	0.150	0.620	
ULTIMATE LEVEL	1.240	0.10	0.170	0.053	5.000

BUILDING REPLACEMENT COST \$ 17250000.

ESTIMATED TOTAL DAMAGE TO BUILDING 60.1 PERCENT

ESTIMATED COST OF DAMAGE \$ 10380682.

DAMAGE ESTIMATES FOR VARIOUS LEVELS OF MAXIMUM GROUND ACCELERATIONS

MAX GRND ACCL. G	TRANSVERSE DIRECTION			LONGITUDINAL DIRECTION			COMBINED DAMAGE PCNT	DAMAGE EST 1000 \$
	SPECTRAL YIELD G	ACCEL ULT. G	DAMAGE PCNT	SPECTRAL YIELD G	ACCEL ULT. G	DAMAGE PCNT		
0.14	0.095	0.001	0.0	0.352	0.030	59.0	39.3	6785
0.19	0.128	0.001	0.0	0.477	0.040	71.6	47.7	8240
0.25	0.169	0.002	19.8	0.628	0.053	80.3	60.1	10380
0.35	0.237	0.003	0.0	0.126	0.011	0.0	0.0	0
0.45	0.304	0.003	0.0	0.251	0.021	40.5	27.0	4657
0.50	0.338	0.003	0.0	0.377	0.032	62.1	41.4	7149
0.20	0.135	0.001	3.2	0.502	0.042	73.4	50.0	8630
0.25	0.169	0.002	19.8	0.628	0.053	80.3	60.1	10380
0.30	0.203	0.002	31.5	0.754	0.064	95.0	67.2	11596
0.35	0.237	0.002	40.3	0.879	0.074	88.4	72.4	12490
0.40	0.270	0.003	47.1	1.005	0.085	90.9	76.3	13175
0.45	0.304	0.003	52.6	1.130	0.095	92.9	79.5	13717
0.50	0.338	0.003	57.0	1.256	0.106	94.5	82.0	14157



**D-9. Examples of the RSAP**

The RSAP is illustrated by means of two examples. One is a steel building and the other is a concrete building. Table D-5 gives the response spectra data for both examples. Table D-6 gives the damage

estimates for the steel building and table D-7 gives the estimates for the concrete building. Figures D-3 and D-4 give the building descriptions and the RSAP calculations for the steel and concrete buildings, respectively.

Table D-5. Response spectra for steel building, example 1.

### DAMAGE ESTIMATES FOR VARIOUS LEVELS OF EARTHQUAKE

#### DAMAGE ESTIMATE FOR VARIOUS BUILDINGS AT NSY LONG BEACH

#### DIGITIZED SITE RESPONSE SPECTRA FOR 0.25 G

PERIOD	PERCENT OF CRITICAL DAMPING				
	0 PCNT	2 PCNT	5 PCNT	10 PCNT	20 PCNT
0.00	0.25	0.25	0.25	0.25	0.25
0.04	0.25	0.25	0.25	0.25	0.25
0.05	0.45	0.34	0.30	0.28	0.26
0.10	1.15	0.64	0.48	0.38	0.32
0.15	1.52	0.89	0.65	0.44	0.39
0.20	1.66	0.99	0.75	0.55	0.42
0.25	1.75	1.06	0.79	0.60	0.46
0.30	1.80	1.09	0.82	0.63	0.48
0.35	1.81	1.10	0.83	0.63	0.49
0.40	1.79	1.08	0.81	0.62	0.47
0.45	1.75	1.05	0.77	0.58	0.44
0.50	1.69	1.00	0.74	0.54	0.42
0.55	1.60	0.94	0.69	0.51	0.39
0.60	1.51	0.88	0.64	0.48	0.37
0.65	1.40	0.82	0.61	0.46	0.34
0.70	1.29	0.77	0.57	0.43	0.32
0.75	1.21	0.72	0.54	0.41	0.30
0.80	1.12	0.68	0.51	0.39	0.29
0.85	1.01	0.63	0.48	0.36	0.26
0.96	0.93	0.59	0.44	0.34	0.05
1.04	0.86	0.54	0.41	0.31	0.24
1.12	0.79	0.50	0.39	0.29	0.23
1.20	0.73	0.47	0.36	0.27	0.22
1.28	0.68	0.44	0.34	0.26	0.21
1.35	0.64	0.42	0.32	0.25	0.20
1.44	0.61	0.40	0.30	0.23	0.19
1.52	0.58	0.37	0.28	0.22	0.18
1.60	0.55	0.35	0.27	0.21	0.17
1.65	0.53	0.34	0.26	0.20	0.17
1.76	0.51	0.32	0.24	0.19	0.16
1.84	0.48	0.31	0.23	0.18	0.15
1.92	0.46	0.30	0.22	0.18	0.14
2.00	0.44	0.28	0.21	0.17	0.13

Table D-6. Output for steel building, example 1.

DAMAGE ESTIMATES FOR VARIOUS LEVELS OF EARTHQUAKE									
DAMAGE ESTIMATE FOR VARIOUS BUILDINGS AT MSY LONG BEACH									
BLDG 131 PIPE AND COPPER SHOP									
BUILDING PROPERTIES AND DAMAGE ESTIMATE FOR A NOMINAL ACCELERATION JF 0.25 G									
TRANSVERSE DIRECTION		PERIOD	DAMPING	SA STR CAPACITY	SA STR DEMAND	R			
		(SEC)		(G)	(G)				
YIELD LEVEL		0.410	0.05	0.610	0.002				
ULTIMATE LEVEL		0.750	0.10	0.610	0.002	5.000			
LONGITUDINAL DIRECTION									
YIELD LEVEL		0.440	0.05	0.130	0.770				
ULTIMATE LEVEL		1.030	0.10	0.210	0.046	5.000			
				BUILDING REPLACEMENT COST \$ 3428000.					
				ESTIMATED TOTAL DAMAGE TO BUILDING 65.1 PERCENT					
				ESTIMATED COST OF DAMAGE \$ 2231785.					
DAMAGE ESTIMATES FOR VARIOUS LEVELS OF MAXIMUM GROUND ACCELERATIONS									
TRANSVERSE DIRECTION		LONGITUDINAL DIRECTION							
MAX GRND ACCL. G	SPECTRAL ACCEL		DAMAGE PCNT	SPECTRAL ACCEL		DAMAGE PCNT	COMBINED DAMAGE PCNT	DAMAGE EST 1000 \$	
	YIELD G	ULT. G		YIELD G	ULT. G				
0.14	3.449	0.046	0.0	0.436	0.026	62.4	41.5	1426	
0.19	0.610	0.062	15.4	0.591	0.035	72.5	53.3	1833	
0.25	3.002	0.082	35.6	0.778	0.046	79.9	65.1	2231	
0.35	3.160	0.016	0.0	0.156	0.009	11.3	7.5	258	
0.10	3.321	0.033	0.0	0.311	0.019	44.6	32.4	1111	
0.15	3.081	0.049	0.0	0.467	0.029	64.9	43.3	1493	
0.20	3.642	0.066	19.5	0.622	0.037	74.0	55.4	1914	
0.25	3.002	0.082	35.6	0.778	0.046	79.9	65.1	2231	
0.30	3.962	0.078	46.3	0.934	0.056	83.9	71.5	2453	
0.35	1.123	0.115	55.3	1.083	0.065	86.9	76.4	2617	
0.40	1.203	0.131	61.8	1.245	0.074	89.2	80.0	2743	
0.45	1.444	0.148	66.3	1.400	0.084	91.0	82.9	2842	
0.50	1.604	0.164	71.0	1.556	0.093	92.4	85.3	2923	

Table D-7. Output for concrete building, example 2.

DAMAGE ESTIMATES FOR VARIOUS LEVELS OF EARTHQUAKE

DAMAGE ESTIMATE FOR VARIOUS BUILDINGS AT MSY LONG BEACH

BLDG 129B MARINE MACHINE

BUILDING PROPERTIES AND DAMAGE ESTIMATE FOR A NOMINAL ACCELERATION OF 0.25 G

	PERIOD (SEC)	DAMPING	SA STR CAPACITY	SA SITE DEMAND	R
TRANSVERSE DIRECTION			(G)	(G)	
YIELD LEVEL	0.080	0.05	0.320	0.404	
ULTIMATE LEVEL	1.160	0.10	0.480	0.502	1.000
LONGITUDINAL DIRECTION					
YIELD LEVEL	3.070	0.05	0.340	0.372	
ULTIMATE LEVEL	7.140	0.10	0.510	0.468	1.000

BUILDING REPLACEMENT COST \$ 445000.  
 ESTIMATED TOTAL DAMAGE TO BUILDING 81.1 PERCENT  
 ESTIMATED COST OF DAMAGE \$ 3612159.

DAMAGE ESTIMATES FOR VARIOUS LEVELS OF MAXIMUM GROUND ACCELERATIONS

MAX GND ACCL. G	TRANSVERSE DIRECTION			LONGITUDINAL DIRECTION			COMBINED DAMAGE PCNT	DAMAGE EST 1000 \$
	SPECTRAL YIELD G	ACCEL ULT. G	DAMAGE PCNT	SPECTRAL YIELD G	ACCEL ULT. G	DAMAGE PCNT		
0.14	1.228	0.281	0.0	0.308	0.262	0.0	0.0	0
0.19	1.310	0.382	0.0	0.283	0.356	0.0	0.0	0
0.25	1.404	0.502	100.0	0.372	0.468	43.2	81.1	3612
0.05	1.082	0.160	0.0	0.074	0.094	0.0	0.0	0
0.10	1.163	0.201	0.0	0.149	0.187	0.0	0.0	0
0.15	1.245	0.301	0.0	0.223	0.261	0.0	0.0	0
0.20	1.326	0.402	7.5	0.298	0.374	0.0	5.0	224
0.25	1.408	0.502	100.0	0.372	0.468	43.2	11.1	3612
0.30	1.490	0.602	100.0	0.446	0.562	100.0	100.0	4454
0.35	1.571	0.703	100.0	0.519	0.699	100.0	100.0	4454
0.40	1.653	0.803	100.0	0.593	0.749	100.0	100.0	4454
0.45	1.734	0.904	100.0	0.670	0.842	100.0	100.0	4454
0.50	1.816	1.004	100.0	0.744	0.936	100.0	100.0	4454

## Building 131 - Pipe and Copper Shop

### Building Data

One-story steel frame building  
Drawn in 1940  
122 ft X 402 ft in plan X 31.5 ft high

### Construction

Laterally braced steel frames  
Composition roof supported by steel trusses  
and bracing.  
Rivet connections

Foundation consists of concrete slab supported  
on concrete piles.

Lateral force resisting system :

Steel frames with vertical bracing  
in the longitudinal direction

### Beam-Girder System

Beams :

6 - W 21 X 59  
27 - W 24 X 74

Crane girders:

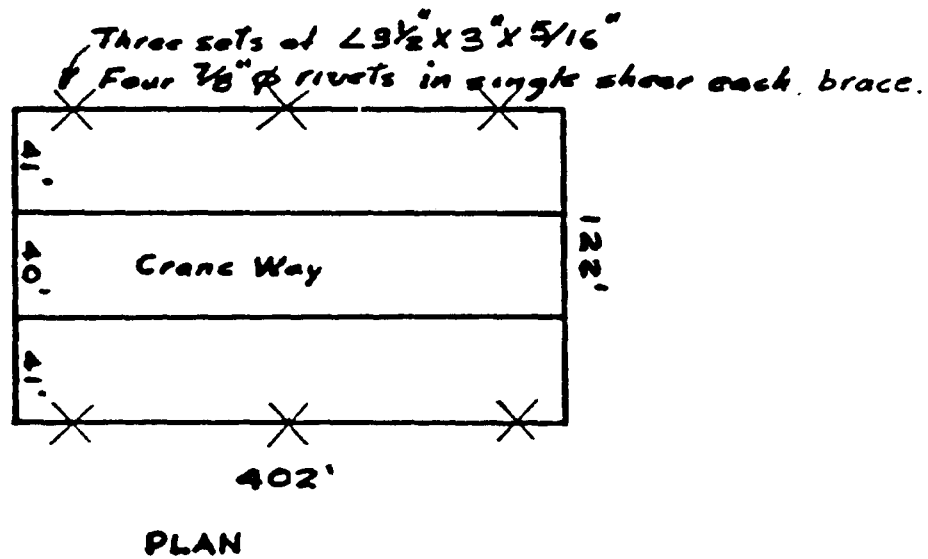
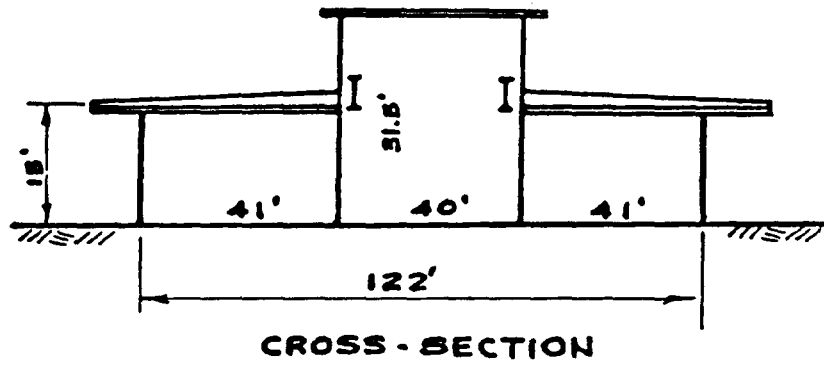
20 - W 30 X 116

### Columns

22 - W 10 X 33  
22 - W 18 X 45

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Figure D-3. Example of steel building. (Sheet 1 of 7)



Sheet 2 of 7

Figure D-3. Example of steel building. (Sheet 2 of 7)

### Weights

Roof & framing	25 psf	
Walls	10	
Misc	5	
	<u>40 psf</u>	Area
		$\times (122' \times 402') = \underline{\underline{1961.8^k}}$

### Spectral Acceleration Capacities $F_y = 36. \text{ ksi}$

#### Columns

$$h_{eff} = 15' / 2 = 7.5'$$

W 10 x 33

$$v_x = \frac{F_y S_{xx}}{h_{eff} (12\%)} = \frac{36. \text{ ksi} (25 \text{ in}^2)}{7.5' (12\%)} = 14. \text{ k/col.}$$

$$v_y = \frac{F_y S_{yy}}{h_{eff} (12\%)} = 14. \text{ k} \left( \frac{9.16}{35.} \right) = 3.66 \text{ k/col.}$$

W 18 x 45

$$v_x = 14. \text{ k/col.} \left( \frac{79.0}{35.0} \right) = 31.6 \text{ k/col.}$$

$$v_y = 14. \text{ k/col.} \left( \frac{9.32}{35.} \right) = 3.73 \text{ k/col.}$$

At yield :

$$\text{Long. : } V_{rc_l} = 22 \text{ col.} (3.66 \text{ k/col.} + 3.73 \text{ k/col.}) = 162.6 \text{ k}$$

$$\text{Trans. : } V_{rc_t} = 22 \text{ col.} (14. \text{ k/col.} + 31.6 \text{ k/col.}) = 1003.2 \text{ k}$$

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Figure D-3. Example of steel building. (Sheet 3 of 7)

At ultimate :

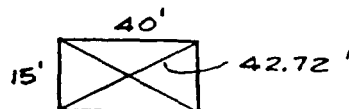
$$\text{Long: } V_{uc_l} = 1.5 V_{yc_l} = 1.5 (162.6^k) = 243.9^k$$

$$\text{Trans: } V_{uc_t} = 1.2 V_{yc_t} = 1.2 (1003.2^k) = 1203.8^k$$

Diagonal Braces. Only effective in tension

Six sets of  $\angle 3\frac{1}{2}" \times 3" \times 5/16"$ .  
Each set is connected by four  $7/8"$   $\phi$  rivets in single shear.

$$A = 3.0 \text{ in}^2$$



Brace :

$$P_L = f_y A \left( \frac{40'}{42.72} \right) = 36 \text{ ksi} (3.0 \text{ in}^2) \left( \frac{40'}{42.72} \right) = 101.1^k / \text{brace}$$

Four  $7/8"$   $\phi$  rivets :

$$S_r = 4 A f_v \left( \frac{40'}{42.72} \right) = 4 \left( \frac{\pi}{4} \right) (0.875)^2 (18.75 \text{ ksi}) \times \left( \frac{40'}{42.72} \right) = 42.2^k / \text{brace}$$

Controls.

Strength of the six diagonal braces :

$$S_b = 6 (42.2^k) = \underline{253.2^k}$$

Neglect contribution from siding.

Totals

At yield :

$$\text{Long: } S_{av_l} \div C_{Br_l} = \frac{253.2^k}{1961.8} = \underline{0.13}$$

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Figure D-3. Example of steel building. (Sheet 4 of 7)

$$\text{Trans. : } S_{ay_t} = \frac{1003.2^k}{1961.8^k} = \underline{\underline{0.51}}$$

At ultimate :

$$\text{Long. : } S_{au_l} = \frac{253.2^k + 162.6^k}{1961.8^k} = \underline{\underline{0.21}}$$

$$\text{Trans. : } S_{au_t} = \frac{1203.8^k}{1961.8^k} = \underline{\underline{0.61}}$$

### Natural Periods

At yield

$$T_y = 2\pi \sqrt{\frac{m}{k}}$$

$$m = \frac{W}{g} = \frac{1961.2^k}{32.2} = 60.9^k\text{-sec}^2/\text{ft}$$

Column stiffnesses :

$$k_c = \sum \frac{12EI}{L^3}$$

$$\begin{aligned} \text{Long. : } k_{cl} &= 22 \left[ \frac{12(30 \times 10^3)}{(15.)^3(144)} \right] (36.5 + 34.8) \\ &= 1,161.^k/\text{ft} \end{aligned}$$

$$\begin{aligned} \text{Trans. : } k_{ct} &= 22 \left[ \frac{12(30 \times 10^3)}{(15.)^3(144)} \right] (171. + 706.) \\ &= 14,289.^k/\text{ft}. \end{aligned}$$

Bracing stiffness :

$$\begin{aligned} k_{dl} &= \frac{AE}{L} \left( \frac{40.}{42.72} \right)^2 = \frac{3.(30 \times 10^3)}{42.72} \left( \frac{40.}{42.72} \right)^2 \\ &= 1847.0^k/\text{ft} / \text{brace} \end{aligned}$$

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Figure D-3. Example of steel building. (Sheet 5 of 7)



$$k_{d_e} = 6 (1847.0 \text{ k/ft}) = 11,082 \text{ k/ft}$$

Long. :

$$k_e = k_{d_e} + k_{c_e} = 11,082 \text{ k/ft} + 1,161 \text{ k/ft} \\ = 12,243 \text{ k/ft}$$

$$T_{ye} = 2\pi \sqrt{\frac{60.9 \text{ k-sec}^2/\text{ft}}{12,243 \text{ k/ft}}} = \underline{\underline{0.44 \text{ sec}}}$$

Trans. :

$$T_{ye} = 2\pi \sqrt{\frac{60.9 \text{ k-sec}^2/\text{ft}}{14,289 \text{ k/ft}}} = \underline{\underline{0.41 \text{ sec}}}$$

At ultimate

Long. : Only the column stiffnesses are effective

$$T_{u_p} = 0.44 \sqrt{\frac{1,161}{12,243}} = \underline{\underline{1.43 \text{ sec}}}$$

Trans. :

$$T_{u_t} = 0.41 \sqrt{\mu \left( \frac{S_{ay_t}}{S_{au_t}} \right)} = 0.41 \sqrt{4/1.2} \\ = \underline{\underline{0.75 \text{ sec}}}$$

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Figure D-3. Example of steel building. (Sheet 6 of 7)

Summary

	$T(sec.)$	$S_a'(g)$
At Yield		
Long.	0.44	0.13
Trans.	0.41	0.51
At Ultimate		
Long.	1.43	0.21
Trans	0.75	0.61

The response spectra used to load the building is given in Table D-5.

Computer output for the building is shown in Table D-6. . . The combined damage for the building at 0.25 g is 65.1%. Hence, the building requires strengthening. This can be accomplished by welding the existing diagonal brace connections and/or the installation of new diagonal braces.

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Figure D-3. Example of steel building. (Sheet 7 of 7)

# Building 129 B - Marine Machine Shop

## Building Data

One-story reinforced concrete building with two mezzanines  
 Drawn in 1944  
 172 ft X 275 ft in plan X 34 ft high

## Construction

Reinforced concrete frames and shear walls.  
 Built-up roofing over concrete roof slab.  
 Concrete slab foundation

Lateral-force resisting system :

Reinforced concrete frames and shear walls.

## Beams

No.	Size (in.)
24	14 X 16
24	14 X 28
24	18 X 42
<u>36</u>	<u>18 X 33</u>
Total = 108	16 X 30 = Average

## Columns

No.	Size (in.)
12	14 X 18
12	16 X 16
24	18 X 24
<u>12</u>	<u>18 X 30</u>
Total = <u>60</u>	18 X 24 = Average

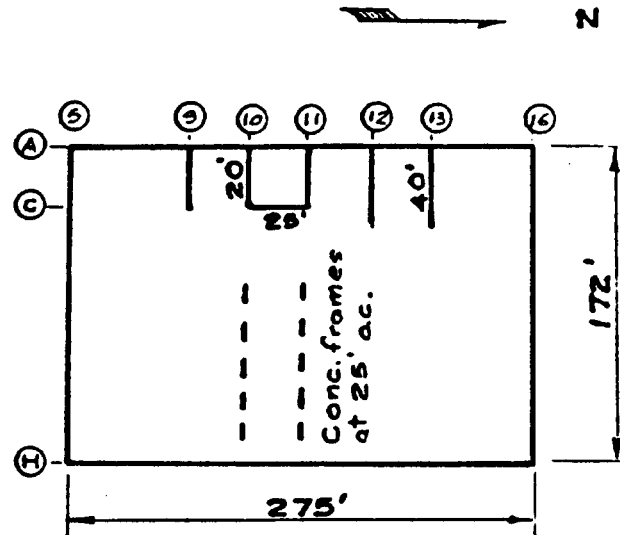
Sheet 1 of 6

Figure D-4. Example of concrete building. (Sheet 1 of 6)

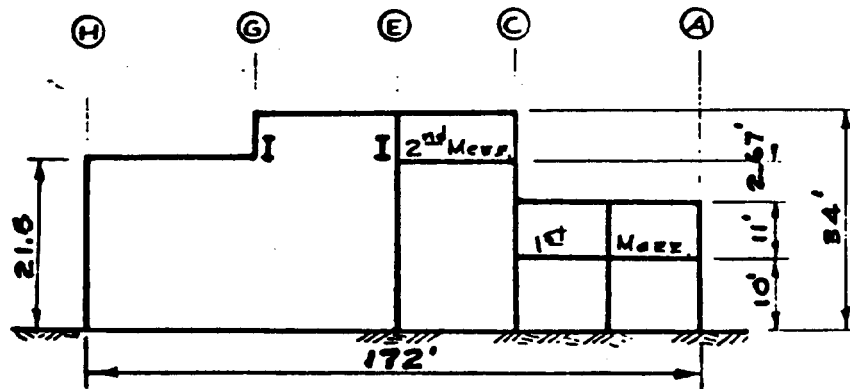
## Shear Walls

Exterior : 8 in. thick with about 50% openings

Interior : 6 in. thick with negligible amount of openings.



## PLAN



### CROSS - SECTION

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**Figure D-4. Example of concrete building. (Sheet 2 of 6)**

## Weights

### Roof

$$\begin{aligned} \text{Beams} \quad & \frac{16 \times 30}{144} (150 \text{ pcf}) = 500 \text{ lb/ft} \\ & \frac{500 \text{ lb/ft}}{25 \text{ ft spacing}} = 20 \text{ pcf} \end{aligned}$$

$$\begin{aligned} \text{Slab} \quad & \frac{6}{12} (150 \text{ pcf}) = 75 \text{ pcf} \\ & \underline{95 \text{ pcf}} \\ & \text{Use } 100 \text{ pcf} \end{aligned}$$

### Walls

1050 linear foot of tributary 15' high  
8 in. thick wall.

$$15' \left( \frac{8}{12} \right) (150 \text{ pcf}) (1059 \text{ ft}) = 158,850 \text{ lb}$$

$$\begin{aligned} & \frac{158,850 \text{ lb.}}{(172')(275')} = 33.6 \text{ pcf} \\ & \text{Use } 35 \text{ pcf} \end{aligned}$$

### Seismic Weight

$$\begin{array}{rcl} \text{Roof \& framing} & 100 \text{ pcf} & \\ \text{Walls} & 35 & \\ \text{Misc.} & \underline{15} & \\ & \underline{150 \text{ pcf}} & \end{array}$$

$$\begin{aligned} \text{Weight} &= 0.150 \text{ pcf} (172')(275') \\ &= \underline{\underline{7095 \text{ k}}} \end{aligned}$$

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Figure D-4. Example of concrete building. (Sheet 3 of 6)

## Spectral Acceleration Capacities

### Assumptions :

1. Ultimate shear strength for concrete columns and shear walls = 100 psi
2. Only one-third of the column cross-sectional area is effective in resisting seismic shear forces.

### Columns

60 - 16" X 24" (Average size) columns

$$A = 16 \times 24 = 384 \text{ in.}^2/\text{col}$$

$$V_{cu} = 384 \text{ in.}^2/\text{col.} (0.1 \text{ ksi}) / 3 = 12.8 \text{ k}/\text{col}$$

$$V_{cu} = 60 \text{ col.} (12.8 \text{ k}/\text{col.}) = \underline{768 \text{ k}}$$

### Shear Walls

$$\begin{aligned} \text{Long. : } & (550 \text{ ft})(12 \text{ in./ft})(8 \text{ in.})(0.5) \\ & + (25 \text{ ft})(12 \text{ in./ft})(6 \text{ in.})(1.0) \\ & = 28,200 \text{ in.}^2 \\ & \times 0.1 \text{ ksi} \\ & V_{swu_l} = \underline{2820 \text{ k}} \end{aligned}$$

$$\begin{aligned} \text{Trans. : } & (344 \text{ ft})(12 \text{ in./ft})(8 \text{ in.})(0.5) \\ & + (140 \text{ ft})(12 \text{ in./ft})(6 \text{ in.})(1.0) \\ & = 26,529 \text{ in.}^2 \\ & \times 0.1 \text{ ksi} \\ & V_{swu_t} = \underline{2659 \text{ k}} \end{aligned}$$

Sheet 4 of 6

Figure D-4. Example of concrete building. (Sheet 4 of 6)

### Total Capacities

#### At Ultimate

$$\begin{aligned} \text{Long. : } S'_{au_l} &\doteq C_{bu_l} = \frac{2820^k + 768^k}{7095^k} \\ &= \underline{\underline{0.51}} \end{aligned}$$

$$\begin{aligned} \text{Trans. : } S'_{au_t} &\doteq C_{bu_t} = \frac{2659^k + 768^k}{7095^k} \\ &= \underline{\underline{0.48}} \end{aligned}$$

#### At Yield

$$\text{Long. : } S'_{ay_l} = \frac{0.51}{1.5} = \underline{\underline{0.34}}$$

$$\text{Trans. : } S'_{ay_t} = \frac{0.48}{1.5} = \underline{\underline{0.32}}$$

### Natural Periods

#### At Yield

$$\begin{aligned} \text{Long. : } T_{y_l} &= \frac{0.05 h_n}{\sqrt{D}} = \frac{0.05(22)}{\sqrt{275}} \\ &= \underline{\underline{0.07 \text{ sec}}} \end{aligned}$$

$$\text{Trans. : } T_{y_t} = \frac{0.05(22)}{\sqrt{172}} = \underline{\underline{0.08 \text{ sec}}}$$

#### At Ultimate

$$\text{Long. : } T_{u_l} \doteq 2 T_{y_l} = 2(0.07) = \underline{\underline{0.14 \text{ sec}}}$$

$$\text{Trans. : } T_{u_t} \doteq 2 T_{y_t} = 2(0.08) = \underline{\underline{0.16 \text{ sec}}}$$

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Figure D-4. Example of concrete building. (Sheet 5 of 6)

Summary

	$T$ (sec.)	$S_a$ (g)
At Yield		
Long.	0.07	0.34
Trans.	0.08	0.32
At Ultimate		
Long.	0.14	0.51
Trans.	0.16	0.48

The response spectra used to load the building was given in Table D-5

The computer output for the building is shown in Table D-7. The damage threshold is at a maximum ground acceleration of about 0.20 g. The estimated combined damage

at 0.25 g acceleration is 81.1%. Thus, the building is inadequate and requires strengthening, particularly in the transverse direction. This can be accomplished by thickening the

existing shear walls with shotcrete and/or the addition of new interior shear walls. Understandably, load paths must be provide to the new shear walls to transfer seismic

forces to them, through them, and into the foundation soil.

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Figure D-4. Example of concrete building. (Sheet 6 of 6)